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Comparison of two methods for evaluating waste of a flow through trout farm

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Abstract:

European water legislation enforces increasingly restrictive measures with regards to reduction of water consumption and waste emission in order to minimise the potential environmental impact of the agro industry sector. Fish farms are particularly concerned, but legislation covering effluent discharge varies significantly from country to country. However, recommendations and directives from institutional, national or regional bodies suggest the enforcement of increasingly strict waste reduction measures and the development of waste treatment. Before treatment, it is necessary to evaluate waste production in terms of composition and quantity. The waste quantification methods used today for fish culture systems are either based on direct measurements of nutrient and suspended solid fluxes or on indirect evaluation based on the digestibility coefficients of the feed constituents. The objective of the present study is to evaluate the waste of a freshwater flow through farm using both approaches and to discuss their applicability, drawbacks and advantages from the viewpoints of fish farmers and control authorities. Waste production on the farm was monitored during several 24 hour cycles in order to characterise the effluents of the system. The predictions and measurements for the total nitrogen (TN) parameter were well correlated, but measured and predicted suspended solids (SS) and total phosphorus (TP) values presented a weaker correlation coefficient. The hydrobiological method gives details on the N and P forms of waste but this method is heavy and it is difficult to obtain representative samples and flow rate measurements. The nutritional method is the simplest to use, provided that feed data are available.

Keywords: Waste; Trout farm; Suspended solids; Nitrogen; Phosphorus

Introduction

There are large differences in aquaculture regulations, in waste control and water quality survey methods and in legislation between European countries. In most countries, water quality is monitored by competent authorities and/or by self-monitoring (Fernandes *et al.*, 2000; Bergheim and Brinker, 2003). Most countries have environmental quality standards mainly in relation to water quality and nutrient release. Some, such as Ireland or Norway, have brought in farming limitations based on a maximal stocking density or a maximal yearly feed quantity (Maroni, 2000). The aim of the EC Water Framework Directive (2000/60) is to develop a sustainable policy for environmental protection and especially, to homogenize all the directives or Community decisions adopted since 1975 on the fight against pollution and on the definition of water quality standards. Countries must progressively reduce polluted water emissions and develop monitoring programs with a view to improving water quality before 2015.

Concerning fish farm waste regulations, one may distinguish two different approaches: one based on a maximal authorized feed quantity; the other on maximal authorized emissions in the recipient ecosystem. In Denmark for example, the Danish decree (2002, November, 8th) fixed: (1) a maximal authorized annual feed quantity for freshwater farms, reduced or increased depending on water abundance and natural quantity and on the effluent treatment system, and (2) feed composition (energy, N, P and ash). A limit has been set on the tonnage of total nitrogen and phosphorous released into marine waters also (Pedersen, 1999). In France, the “polluter payer” principle implies that fish farmers must pay a tax to the regional water agencies. The payment is calculated on annual feed quantity and suspended solids (SS), nitrogen (N) and phosphorous (P) fluxes, with global emission coefficients obtained from feed digestibility determinations. Fish farm effluents are also regulated by the French ICPE

legislation (Classified Installations for the Protection of the Environment)[1]. This concerns fresh water farms and seawater farms with annual production above 10 metric tons and 20 tons respectively. The key element of this legislation is the environmental impact assessment, in which waste quantification is required, and its impact evaluated. Therefore, in view of water legislation changes, fish waste characterisation and quantification are both key elements for fish farm operations and their waste monitoring and treatment.

For this purpose one may consider the particularities and origin of the wastes. Typically, fish waste is characterised by its high level of dilution when compared to other animal production or industrial wastewaters. The wastes first originate from the partial intake by fish or the partial digestibility of feed. When feed is metabolised by fish for energy and growth (including gamete production), as the efficiency of any biological reaction is less than 100%, some catabolites are produced in solid and soluble forms. Solid wastes, comprising faecal matter, constitute a more or less compact settlable material. Their chemical composition (C, N, P) and physical characteristics (size, density, water content...) depend on the feed composition and on the fish (species, phase of development). Large variations in nutrient utilisation by fish have been reported, depending on the type of nutrient (Kaushik, 1998). In addition to solids, faeces contain water and dissolved substances, mainly phosphorus and calcium. Fish also excrete soluble compounds through the gills and kidneys. When lipid and carbohydrate degradation produce CO_2 and water, protein degradation mainly produces ammonia (NH_3 and NH_4^+), representing 80 to 90% of the soluble nitrogen excreted, with the balance being excreted mostly as urea. For most of the fish, nitrogen excretion represents 50 to 70% of the nitrogen intake (Dosdat 1992a, b; Dosdat *et al.*, 1996; Company *et al.*, 1999).

[1] Law No. 76-663 of July 19, 1976 with its decree of application No. 77-1133 of September 21, 1977. ICPE law has been codified in 2000 by the Environmental Code; the law is now abrogated and Book V Title 1st of the Environmental Code is the reference.

The main soluble phosphorus waste is orthophosphate (PO_4^{3-}), representing only about 20% of the phosphorus intake (Dosdat *et al.,* 1996).

According to these characteristics, two different methods are used for fish culture systems: (1) a direct method, measuring dissolved and suspended matter in situ fluxes released by the farm, based on a hydrobiological approach and (2) an indirect evaluation, based on a nutritional approach, using defined feed amounts and appropriate digestibility coefficients (Jatteau, 1999).

In France, an expert panel[2] was appointed by the authorities to review the current strategies for evaluation of fish farm wastes (Papatryphon *et al*., 2005). It was agreed that the method currently in use in France (Fauré, 1983) was not accurate enough and therefore should be replaced. This method uses the following equations to calculate waste production from salmonids :

(1) NH_4 ($kg.d^{-1}$) = K * alpha * A, where K is a coefficient taking into account the number of previous water utilization (n) with K= 0.8 + 0.2 * n, A is the daily quantity of feed distributed ($kg.d^{-1}$), and alpha the NH_4 production rate.

(2) SS ($kg.d^{-1}$) = (1 – Kd) (33 * IC - 20) * A / 100, where Kd is the fish farm decantation coefficient and IC is the feed conversion ratio.

(3) TP ($kg.d^{-1}$) = 0.0048 * A.

The expert panel recommended a nutrient-balance model based on work by Cho *et al*. (1991), Cho and Bureau (1998) and Kaushik (1980, 1998). They carried out an initial validation of the model using data collected in 19 farms (self monitoring data and punctual measurements). This approach is based on the evaluation of the fish waste production through the digestibility

[2] including scientists and representatives from (1) the French National Institute for Agricultural Research (INRA), the French Research Institute for the Exploitation of the Sea (IFREMER), (2) the feed manufacturing sectors, (3) the French Aquaculture Federation (FFA) and the Inter-Professional Committee of Aquaculture Products (CIPA)

of the distributed feed: waste production is given by the difference between the quantity of nutrient ingested and the part kept by the fish for its body gain.

The hydrobiological approach is based on the water flow rates and concentrations measured at the inlet and the outlet of the fish farm. Dissolved and particulate fluxes are calculated by subtracting the inlet flow from the outlet flow (Liao, 1970 and Liao and Mayo, 1974). Several studies were carried out (Fauré, 1983; Tarazona *et al*., 1993, Kelly *et al*., 1994; Lemarié *et al*., 1998), but the results were established for few fish species and feed compositions, while composition and digestibility coefficients change over time.

Boujard *et al*. (1999) compared the results of waste evaluation using the nutritional and hydrobiological approaches on several rainbow trout breeding tanks. Nutrient concentrations and flow rate measurements were carried out two times, during two consecutive days, with water sampling and flow rate measurements every two hours. Water sampling and flow rate measurements methods are not described in the publication. Good correlations between measured and predicted values were found, but they found that the predicted values were always underestimated. Papatryphon *et al*. (2005) compared values predicted by a nutrient-balance model with fluxes calculated from nutrient concentrations measured in the recipient river. The water flow rates and nutrient concentrations were not directly measured during the study but were collected from farmers or water agency records. They found a good correlation, but a tendency to overestimate the predicted NH_4^+ and P values.

This approaches raise the problem of (1) synchronization between nutrient concentrations and flow rate measurements and (2) the accuracy of the water flow rates and nutrient concentration measurements, which are the two key elements to evaluate waste fluxes.

In this study, in order to optimise the accuracy on the mass balance evaluation, our approach consisted in simultaneous measurements of nutrient concentrations and flow rates, 4 times during 24h periods, using the same methodology and measurements devices located at the

same sampling spots. Continuous data acquisition equipment was used in order to optimise the precision of the measurements.

The first objective of our study was to compare the nutrient fluxes obtained using both current approaches in order to evaluate the waste produced by a whole flow through farm, with continuous sampling during several 24 hour periods in order to characterise the daily waste fluxes.

The second objective was to discuss the applicability of both waste evaluation approaches for the fish farmers and control authorities, as tools for the waste quantification which is required in the French ICPE legislation.

Materials and methods

The investigation took place in 2005-2006 on the on-growing unit of the Charles Murgat SA trout farm, located at Beaurepaire in south east France. The farm is operated using the flow through system and produces on average 600 tons of brook trout, brown trout, rainbow trout and arctic char per year, at a fish stocking density of around 58 $kg.m^{-3}$.

The on-growing unit is divided into two sectors (figure 1):

- sector 1 is composed of 7 concrete raceways (each 70*6*0.8 m), with 4 species reared from 50 g to more than 2000 g. Each tank is divided into batches, each comprising different species, at different sizes, corresponding to the market demand. During the studied period, 55 to 70 % of the fish weighed around 200 g and the average feed conversion ratio (FCR) was 0.85.
- sector 2 is composed of 2 concrete raceways, with only rainbow trout species (from 200 g to 1000 g,). The average weight of 50 % of the population is around 500 g and the average FCR is 0.95.

Both sectors use very high quality, constant temperature well water (around 10 °C during the period). The first three tanks of sector 1 are fed with a well water flow rate varying from 600 $l.s^{-1}$ up to 2000 $l.s^{-1}$, corresponding to a water renewal rate of between 200 % and 600 % per hour in the tanks. After a first use, the rearing water is filtered through a mechanical filter, oxygenated, and reused in the four following tanks of the sector 1. Each tank is equipped with several aerators in order to keep the oxygen concentration above 5 mg $O_2.l^{-1}$ in the tank outlet. The effluent of that sector is filtered with another drum filter before being released into the river through a sport fishing area. The two tanks of sector 2 are fed with the same well water, with a flow rate varying around 500 $L.s^{-1}$.

In this study the wastes produced by the two on-growing units (sectors 1 and 2) of the farm were evaluated using the hydrobiological and the nutritional methods.

The "hydrobiological" method

The hydrobiological method is based on water sampling and flow rate measurements. In order to optimise the accuracy of the flow rate measurement, it was decided to measure the water velocity in the tanks which are easily accessible, have a well defined cross section) and a more homogeneous hydraulic regime than the water inlet and outlet channels. Four 24h sampling periods were performed on sectors 1 and 2 between January and March 2006, the last one only on sector 1 (sector 2 was not sampled because of important fishing events). The sampling period was fixed for 24h because the feeding ratio is stable over a period of two days. The inlet and the outlet waters of the two sectors were sampled by ISCO 6712 automatic sampler over 24h, with a frequency of one sample every 30 minutes in order to follow the daily fluctuations of waste concentrations linked to the feeding periods (Hennessy et al, 1996). Water samples were stored 24 hours at 4°C before analysis. In water samples, dissolved N and P, particulate N and total P and suspended solids concentrations were measured.

Dissolved N and P were measured by spectrophotometry, after filtration on Whatman GF/C filters. NH_4-N, NO_2-N, urea-N, PO_4-P were analysed using an Alliance Instruments Evolution II, after AFNOR method (NF T 90-015) described by Solorzano (1969) and the ISO method (6777-1984 F) described by Bendschneider and Robinson (1952) respectively. NO_3-N was measured with a Technicon® Autoanalyzer II, after a nitrite reduction on a cadmium-copper column (Wood *et al.*, 1967).

Particulate-N was obtained after a CHN analysis and total-P by using a colorimetric method NFENISO11885 (after mineralisation). Total N was calculated by adding the nitrogenous compound concentrations. Suspended solid (SS) concentrations were determined after GF/C filtration (NFEN872).

During the sampling periods, the water flow rates were measured with a bottom mounted Argonaut- shallow water Doppler current meter (Huhta and Ward, 2003). This current meter provides a vertically integrated velocity measurement (4 points of measurement in the water column). The water flow rates were measured in the 9 tanks of the farm, which constitute the two sectors, with a frequency of one sample every 15 seconds. The current meter was placed on the bottom of the tanks and moved at different distances of the vertical walls (every 50 cm) during the 24 hour period. These measures enabled calculation of the average water flow rate of the farm. The effluent (dissolved, particulate and SS) fluxes produced by the fishes during the 24 hour period were calculated by subtraction of inlet fluxes from outlet fluxes.

Temperature, oxygen, pH and redox were also controlled with a Consort multi-parameter analyser.

The "nutritional" method

Fish farm effluent production was calculated with the nutrient balance model developed by Papatryphon *et al.* (2005). This model is based on feed utilisation by the fish. Waste fluxes

192 are calculated by removing the part retained by the fish (biomass production and body
193 composition), from the part ingested by the fish.
194 Total effluents include solid and dissolved effluents, with solid effluents as the undigested
195 part of the feed (calculated with the nutrient digestibility coefficients (Guillaume *et al.*,
196 1999)), and dissolved effluents as the rest. The total-SS are calculated by adding the faecal
197 SS, equivalent to the non digested feed (proteins, lipids, carbohydrates, ash and fibres) and the
198 SS from uneaten feed. In this method, the following equations are used to calculate N, P and
199 SS waste production:
200 **(1) Total nitrogen = solid nitrogen + dissolved nitrogen**
201 **Solid N** = Faecal N + Uneaten N
202 Faecal N =[(DF – (DF * % UF)] * (% protein / 6.25) * (100 – DC) %
203 Uneaten N =(DF * % UF) * (% protein /6.25)
204 With: DF = distributed feed, UF = uneaten feed, % protein = proportion of protein in feed,
205 DC = digestibility coefficient
206 **Dissolved N** = consumed N – faecal N – digested part of N
207 Consumed N = DF – (DF * % UF)] * (% protein / 6.25)
208 Digested part N = DF * BN / FCR
209 With BN = Whole fish body N content = 0.0256-0.0272 g/g of body weight (Papatryphon et
210 al, 2005); FCR = Feed Conversion Ratio. The dissolved NH_4N is calculated with an 80 %
211 coefficient corresponding to the proportion of NH_4N in total dissolved N excretion
212 (Papatryphon et al, 2005).
213 Similar equations with appropriate coefficients are used to evaluate P wastes: the proportion
214 of phosphorus in feed composition and the whole fish body P content of 0.004 g/g of body
215 weight (Papatryphon et al, 2005).
216

(2) **Total SS = faecal SS + uneaten feed SS**

Faecal SS = Non digested proteins + Non digested lipids + Non digested carbohydrates + Non digested ash + Non digested fibres

$$=[(DF - (DF * \% UF)] * \sum [\% \text{ nutriment x } (100\text{-}DC)\%]$$

Uneaten feed SS = (DF * % UF) * (% dry matter in feed)

The digestibility coefficients (DC) were those proposed by Papatryphon et al., 2005 (table I); protein and lipid digestibility coefficients were compared to the digestibility coefficient measured by the manufacturer.

Fish were fed twice a day around 1 % of the standing stock per day, with two different feed origins according to the fish size. The average feed composition is presented on table I. Fish were fed partly automatically, partly manually, up to satiety. The daily feed quantity distributed manually was determined from feeding tables by a computerised distribution system. The complementary quantity distributed manually up to satiety was also registered. This feeding method allowed avoiding uneaten feed. Tank biomass was evaluated from the biometrics every other week (average weight on 50 fish, for each batch) and enabled calculation of the FCR. Body nutrient contents were set on 26 g N. kg^{-1} of body weight and 4 g P. kg^{-1} of body weight (Papatryphon *et al.*, 2005).

Results

Daily feed rate and tank biomass were stable during the studied period. The biological data are presented in table II. The water flow rate of the whole farm fluctuated around 1336.7 ± 210.8 $l.s^{-1}$ (average daily flow rates of 820, 840, 1030 and 857 $l.s^{-1}$ on sector 1, during the four 24 h periods respectively, and 400, 370 and 550 $l.s^{-1}$ on sector 2, during the three 24 h periods). 168 samples were treated.

241 The daily waste fluxes of the farm, predicted with the nutritional method, the CEMAGREF
242 method and measured with the hydrobiological method are presented in table III, with
243 corresponding values expressed as fluxes per kg feed. These data correspond to the waste
244 produced by a standing stock of 132 tonnes of fish (average value during the studied period).
245 The daily average flux of total-N, measured using the hydrobiological method is 54.1 ± 10
246 $kg.d^{-1}$, when the predicted value is 59.82 ± 6.01 $kg.d^{-1}$. The measured daily flux of total-P is
247 13.6 ± 3.5 $kg.d^{-1}$, almost twice the predicted value: 6.33 ± 0.61 $kg.d^{-1}$. The measured daily
248 flux of SS is 317.8 ± 165.7 $kg.d^{-1}$compared to a predicted value of 206.48 ± 20.67 $kg.d^{-1}$. The
249 measured fluxes of particulate-N, NH_4-N and urea-N are respectively 11.8 ± 3.4, 31.6 ± 7.5
250 and 10.7 ± 2.5 $kg.d^{-1}$ and the particulate-P and PO_4-P fluxes produced by the fish are 9.6 ± 3.6
251 and 4.0 ± 0.2 $kg.d^{-1}$ (table III).
252 Using the CEMAGREF method (Fauré, 1983), NH_4-N, TP and SS fluxes of the farm are 36.4
253 ± 3.7, 6.7 ± 0.7, and 136.3 ± 14.1 $kg.d^{-1}$ respectively (table III).
254 Variance of the predicted and measured fluxes represents the variability of the fluxes between
255 each 24 hour period. The figure 2 presents a comparison between predicted and measured
256 fluxes.
257 Figures 3 - 5 show the relation between measured and predicted TN, TP and SS. The
258 measured and predicted TN values are well correlated with $r^2 = 0.88$) whereas the correlation
259 coefficients between measured and predicted TP and SS values are weaker (0.53 and 0.48
260 respectively).
261 The hydrobiological method provides detailed information on the different forms of nitrogen
262 and phosphorous fluxes; 21% of nitrogen wastes are in the particulate form, 59% are NH_4-N
263 and 20% urea-N. 68.8% of the phosphorous wastes are in the particulate form and 31.2% are
264 dissolved PO_4-P.

Concerning the daily fluctuations, NH_4-N flux profiles (figure 6) show higher values during the day and decrease in the night. In spite of a slight NH_4-N increase 4 to 6 hours after the morning feed distribution, the two daily feed distributions seem to reduce the postprandial excretion peak. SS daily fluxes show higher fluctuations (figure 7). There is a time lag between NH_4-N and SS fluxes: SS transit seems to be slower than excretion. The concentrations of other substances are lower and more stable during the day.

Discussion and conclusion

The CEMAGREF method gives lower SS value than the nutritional method and the measured value (Table III and figure 2). This can be explained by excessive variation coefficients of the results of this model, which is not statistically acceptable for the SS (Jatteau, 1999), and by important daily SS fluctuations (figure 7). The predicted daily flux of total-P calculated using the nutritional method is quite similar to the CEMAGREF estimation and lower than the measured value. The NH_4-N fluxes calculated with the three methods are in the same order of magnitude. Even if the CEMAGREF method gives consistent results, this method is only based on the daily quantity of feed distributedand do not take into account the feed composition or the digestibility coefficients, while they are currently drastically improved. In fact, metabolic wastes can be minimised by modifying the digestibility, the energetic density and friability of the feed ingredients (Cho and Bureau, 1997; Kaushik, 1998; Roque d'Orbcastel and Blancheton, in press, 2006). MacMillan *et al.* (2003) attributed 40% of the P effluent reduction of flow-through trout farms, during the past 15 years, to management improvements, such as feeding practices, low-P (0.9%) feed use and frequent tank cleanings (quiescent zone management).

In our study, the total annual waste production estimated with the nutritional method, expressed per metric ton of fish standing stock, were 147.5 kg for solids, 40.8 kg for N, and 8.7 kg for P, lower than those reported by Axler *et al.* (1997) and by Bureau et al. (2003) for salmonid farms (table IV).

Concerning the comparison between the nutritional method and the hydrobiological method results, predicted and measured N waste fluxes are quite similar: the predictions and measurements are well correlated ($r^2 = 0.88$), with predictions a bit higher than measurements. For the TP and SS parameters, the predicted and measured fluxes are less correlated (r^2 of 0.53 and 0.48 respectively), with measurements higher than predictions. The physical properties of solid wastes, subject to decantation as well as re-suspension, can explain part of the differences. According to Boujard *et al*. (1999) and Papatryphon *et al*. (2005), N, P and SS are sometimes underestimated by the hydrobiological method because of sampling difficulties and sample preservation difficulties, and sometimes overestimated, because of solid re-suspension (due to fishing, tank cleaning or hydrology). They can also be under or overestimated by the nutritional method, depending on the digestibility coefficients and the precision of ingested feed quantities.

Boujard *et al*. (1999) compared the results of waste evaluation with the nutritional and the hydrobiological methods (two consecutive 24 h periods, with samples taken every 2 hours, on 4 rainbow trout tanks). They found a global balance of nitrogenous wastes of 50-65 g N.kg $feed^{-1}$ and 9-16 g P.kg $feed^{-1}$ for the phosphorous corresponding value, a bit higher than those found during the present study. In their study, they defined the waste as the fraction of the nutrients which are not retained by the fish, including also the uneaten feed (Boujard, *pers. comm.*). The lower quantities that we measured using the hydrobiological method (38.5 ± 7.1 of total-N $g.kg^{-1}$feed and 9.7 ± 2.5 of total-P), could be explained by better feed management on the Murgat farm which results in almost no uneaten feed. They shown also a good

314 correlation between predicted and measured N values, with r^2 = 0.85, higher than the
315 correlation factor for P values of 0.67. According to the authors, the wastes measured with the
316 hydrobiological method were underestimated but comparable to the calculated values. They
317 attributed this underestimation to the settable characteristic of the suspended solids.
318 Papatryphon *et al.* (2005) compared the predicted values with NH_4^+, TP and SS
319 concentrations measurements in the recipient river. They found waste prediction values well
320 correlated with the measured values, but the trend was an overestimation of predicted NH_4^+
321 and P values, that the authors explained by a probable degradation of NH_4^+ in the samples
322 through nitrification processes. Some observed concentrations in SS were higher than
323 predictions, certainly due to the highly variable solid transport in aquaculture raceways (solids
324 decantation or re-suspension), which depends on the farm management and/or environmental
325 variability such as high flow rate. Maillard *et al.* (2005) observed higher TSS concentrations
326 during harvesting and feeding events (fish agitation) of different raceway system trout farms.
327
328 Both methods present drawbacks and advantages. The hydrobiological method is interesting
329 because it gives details on the different forms of N and P in the wastes (Boujard *et al*., 1999),.
330 The results obtained in this study are comparable to those of previous studies: (Braaten, 1991;
331 Heinen *et al.*, 1996; True *et al.*, 2004) reported that over 85% of N was in dissolved form and
332 40-85% of P in solid form. Boujard *et al*. (1999) found that for 1 kg of dry feed (80-93 g of N
333 and 12-21 g of P) similar results for the N waste proportions (73% of the nitrogen was
334 released, with 78% in NH_4-N form) but opposite for the P wastes (87% of the phosphorous
335 was released with 60% in dissolved form (mainly PO_4-P)).
336 Using the hydrobiological method, we observed important daily NH_4-N and SS fluxes
337 fluctuations (figure 8). In fact, fish farm wastes are highly fluctuating: daily variations
338 depending on feeding time and farm management (fishing, sorting…); annual variations

339 depending on the fish biomass and distributed feed. For example, NH_4 waste increases after
340 the feeding time, with a maximum around 6 hours after feeding, depending on species, feed
341 and feeding ratio and feeding several times a day contributes to decrease the waste daily
342 fluctuation (Dosdat *et al.*, 1996; Jatteau, 1999). SS fluxes increase during the feeding period
343 because of fish motion and may also increase after digestion (after Guillaume *et al*., 1999,
344 ingested feed stays in the gut of 250-500g fishes during about 10 hours after ingestion).
345 Representative samples of the waste produced by the farm cannot be obtained if the number
346 of samples is decreased (Boujard *et al*., 1999; Cho and Bureau, 1997; Jatteau, 1999). Several
347 sampling periods have to be implemented simultaneously in the inlet and outlet of the farm in
348 order to get representative results. Sampling must be done carefully, especially because of the
349 solid matter properties. The AFNOR-NFT90-105 recommends a sample of a minimum
350 volume of 500ml (for fresh water). The samples have to be preserved because of the
351 possibility of nutrient transformation through leaching and bacterial activity.
352 For the hydrobiological method, the main difficulty is the water flow rate measurement, a key
353 point for the flux evaluation but difficult even with a precision equipment. From one tank to
354 another, even if the geometry is the same, the measured flow rate varies by 20%. From one
355 day to another, the variation of the flow rate measurement could be around 35%. The
356 difficulty in evaluating the water flow rate makes current waste control validity questionable.
357 Environmental monitoring is based on the use of indicators, such as the maximum SS, BOD,
358 NH_4 concentrations in the recipient ecosystem. As fluxes are calculated with concentration
359 and flow rate, it seems to be difficult to properly control the correlation between the measured
360 and the predicted values at the farm outlet (with their own uncertainties) as recorded by the
361 farmer in the environmental assessment.
362 The hydrobiological method appears to be too heavy and costly for regular use as part of the
363 waste quantification and self monitoring processes required under the ICPE legislation.

In comparison, the nutritional method is easier and quicker, and a rather inexpensive way to predict fish waste production. Using the theoretical digestibility coefficients (Papatryphon *et al*., 2005) and feed composition given by the manufacturer, or the measured digestibility coefficients (for proteins and lipids) and feed composition, the nutritional method gave different solid waste evaluation. With the theoretical protein, lipid and carbohydrate coefficients and theoretical feed composition, the SS predicted emissions are 88.5 tons / year whereas with measured coefficients, the model gives 69.3 tons / year. So the feed composition and the digestibility coefficients used in the model can lead to more than 20% variation in the solid waste evaluation.

Even if the hydrobiological and nutritional methods do not allow one to precisely anticipate waste production, both provide interesting orders of magnitude; the nutritional method is the simplest for the fish farmers to evaluate the waste produced by their farm, although it requires precise information (especially on feed composition, ingested feed quantity and digestibility coefficients are available).

If it is established that waste emissions can be reduced at the fish level (Cho and Bureau, 1997; Kaushik, 1998; Roque d'Orbcastel and Blancheton, 2006; MacMillan *et al.* 2003), waste also has to be reduced at the system level through the use of well designed waste treatment systems. The design of the treatment systems also requires good knowledge of the waste production process especially because the economic feasibility of aquaculture waste treatment has not yet been demonstrated in most of the situations.

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Table I. fish extruded feed composition (%), theoretical nutrient digestibility coefficients (DC) (from Papatryphon *et al.*, 2005) and calculated digestibility coefficients (%) (Moutounet, *pers. comm.*)

	Mean feed composition (%)	Theoretical DC (%)	Calculated DC (%)
Moisture	8		
Protein	45	90	93
Lipids	27	95	96
Carbohydrate	10.1	60	75
Ash	6.7	50	
Fibre	1.4	0	
Phosphorus	0.9	50	
Energy ($MJ.kg^{-1}$)	21.2		

Table II. Biomass in tanks, daily feed quantities, average feeding rates and FCR of the farm during the different sampling series (last serie only includes the sector 1 results; sector 2 was not sampled because of too important fishing events)

Date	Biomass (kg)	Daily feed ($kg.d^{-1}$)	Average feeding Rate (%)	Average FCR ($kg.kg^{-1}$)
25-26.01.2006	177 449	1314	0.74	0.88
07-08.02.2006	174 412	1333	0.76	0.87
22-23.02.2006	178 571	1568	0.88	0.88
07-08.03.2006	130 643	1012	0.84	0.77

Table III. Daily waste production of the whole farm, predicted according to the nutritional method and measured in situ with the hydrobiological method, expressed in $kg.d^{-1}$ and $g.kg^{-1}$ feed delivered. d^{-1}

Parameter	Measured mean fluxes ($kg.d^{-1}$ ± S.D.)	Predicted mean fluxes ($kg.d^{-1}$ ± S.D.)	Cemagref calculated values ($kg.d^{-1}$ ± S.D.)	Measured mean fluxes ($g.\ kg^{-1}$ feed.d^{-1} ± S.D.)	Predicted mean fluxes ($g.\ kg^{-1}$ feed.d^{-1} ± S.D.)
Suspended solids	317.8 ± 165.7	206.5 ± 20.7	136.3 ± 14.1	226.2 ± 117.9	147.0 ± 0.2
Total nitrogen	54.1 ± 10	59.8 ± 6.0		38.5 ± 7.1	42.6 ± 0.4
Particulate nitrogen	11.8 ± 3.4	10.1 ± 1.0		8.4 ± 2.4	7.2 ± 0.0
Ammonia nitrogen	31.6 ± 7.5	39.7 ± 4.0	36.4 ± 3.7	22.5 ± 5.3	28.3 ± 0.3
Urea nitrogen	10.7 ± 2.5	-		7.6 ± 1.8	-
Total phosphorus	13.6 ± 3.5	6.3 ± 0.6	6.7 ± 0.7	9.7 ± 2.5	4.5 ± 0.1
Particulate phosphorus	9.6 ± 3.6	-		6.8 ± 2.6	-
Orthophosphate-P	4.0 ± 0.2	-		2.8 ± 0.1	-

Table IV. Total annual waste production of the farm calculated with the nutritional method, in comparison with values reported by Axler *et al.* (1997) and Bureau et al. (2003), expressed per metric ton of fish

Parameter	Calculated values (kg. ton^{-1} of fish produced)	Axler *et al.* (1997) values (kg. ton^{-1} of fish produced)	Bureau et al. (2003) values (kg. ton^{-1} of fish produced)
Suspended solids	147.5	289-839	240-318
Total nitrogen	40.8	47-87	47-71
Total phosphorus	8.7	4.8-18.7	7.5-15.2

Figure captions

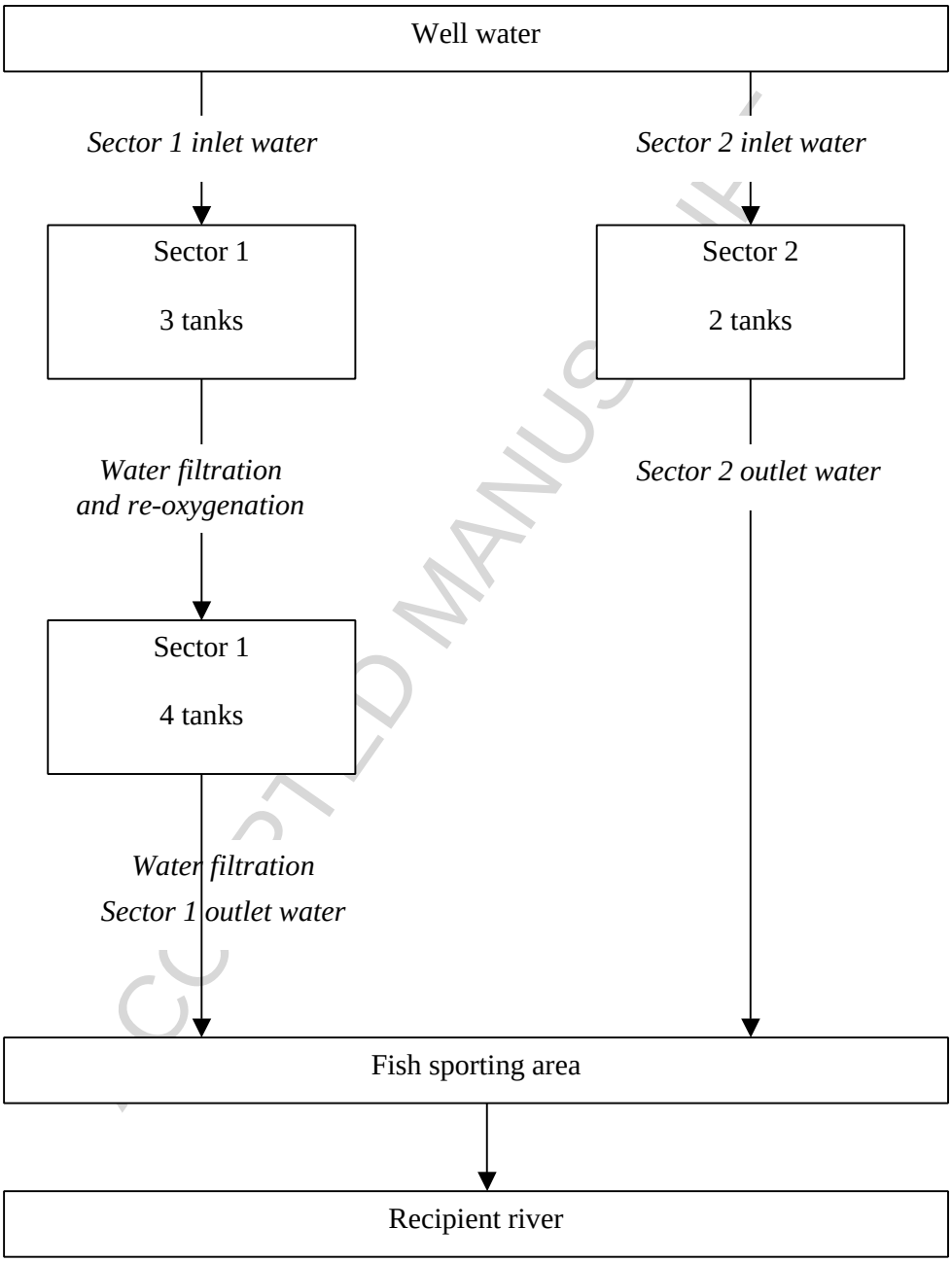

Figure 1. The growing sector of the farm, divided into two sectors: sector 1 composed of 7 concrete tanks with 4 species reared and sector 2 composed of 2 concrete tanks with only rainbow trout species. Each sector is fed by its own well water.

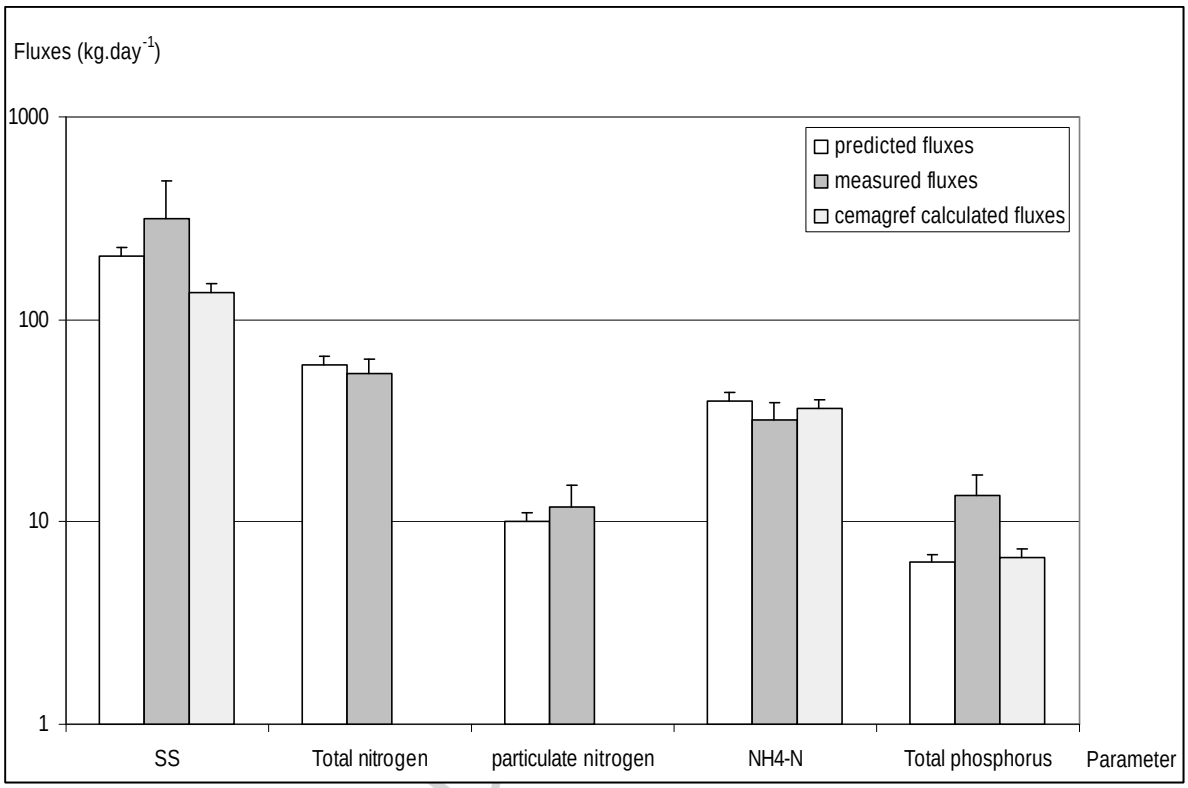

Figure 2. Predicted (nutritional method and CEMAGREF method) and measured fluxes of the farm, expressed in kg per day, with a logarithmic scale.

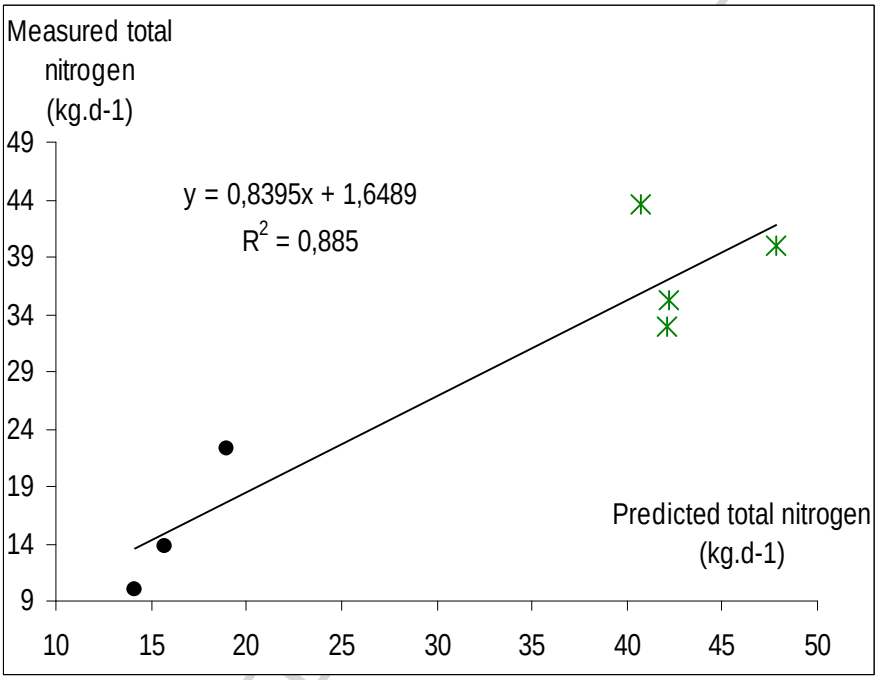

Figure 3. Comparison of the total-N measured values and the total-N predicted values, in the two different areas of the farm (sector 1 values are represented with green stars, sector 2 values with black points). The measured values are obtained from the hydrobiological method, the predicted values from the nutritional method. Total-N is the total-N flux produced by the farm during a day, expressed in kg per day. R^2 is the correlation factor.

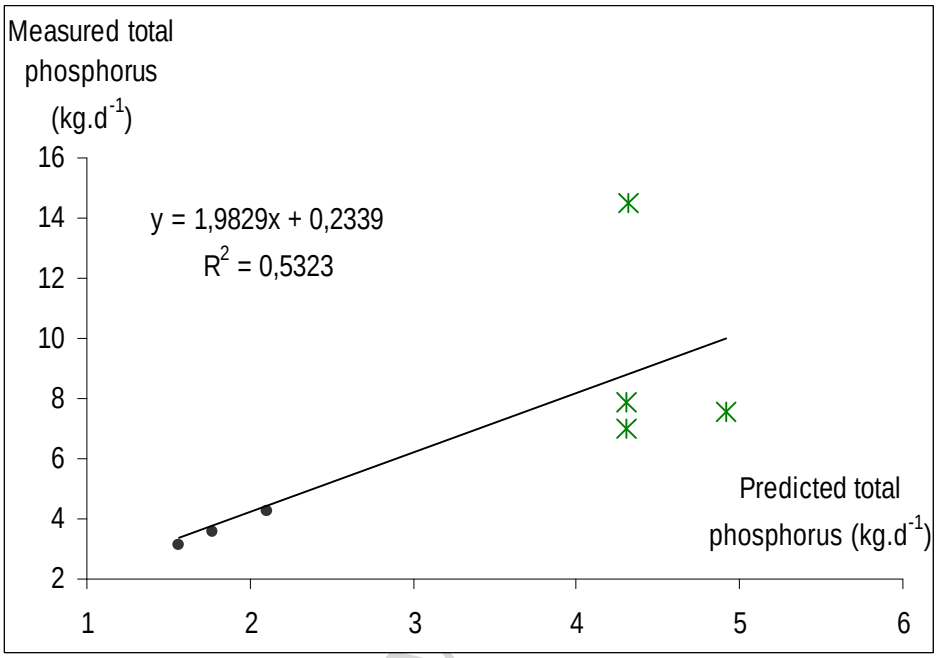

Figure 4. Comparison of the total-P measured values and the total-P predicted values, in the two different areas of the farm (sector 1 values are represented with green stars, sector 2 values with black points). The measured values are obtained with the hydrobiological method, the predicted values with the nutritional method. Total-P is the total-P flux produced by the farm during a day, expressed in kg per day. R^2 is the correlation factor.

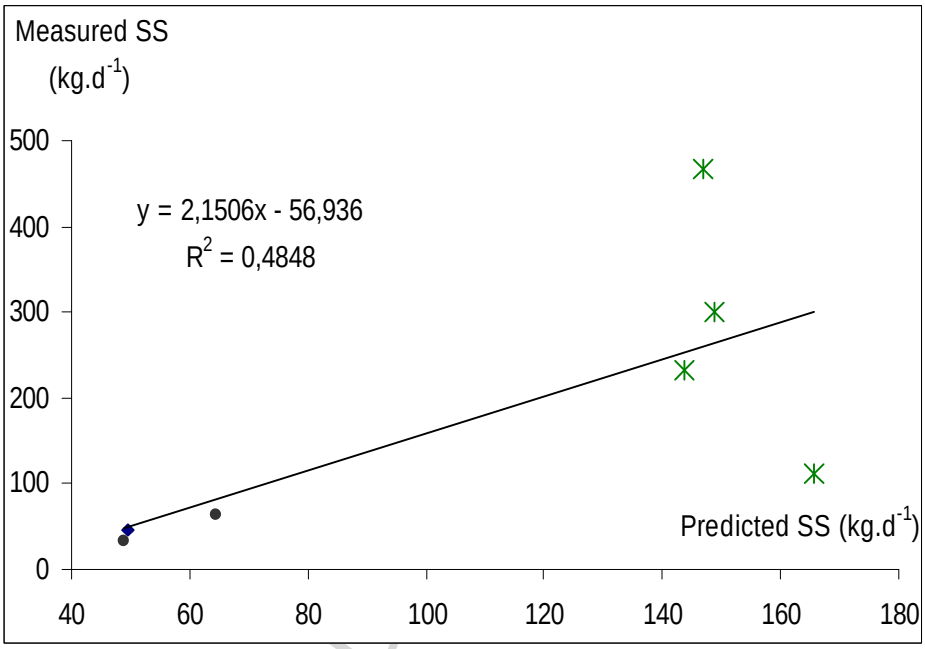

Figure 5. Comparison of the total suspended solid measured values and the total suspended solid predicted values, in the two different areas of the farm (sector 1 values are represented with green stars, sector 2 values with black points). The measured values are obtained with the hydrobiological method, the predicted values with the nutritional method. TSS is the total suspended solid flux produced by the farm during a day, expressed in kg per day. R^2 is the correlation factor.

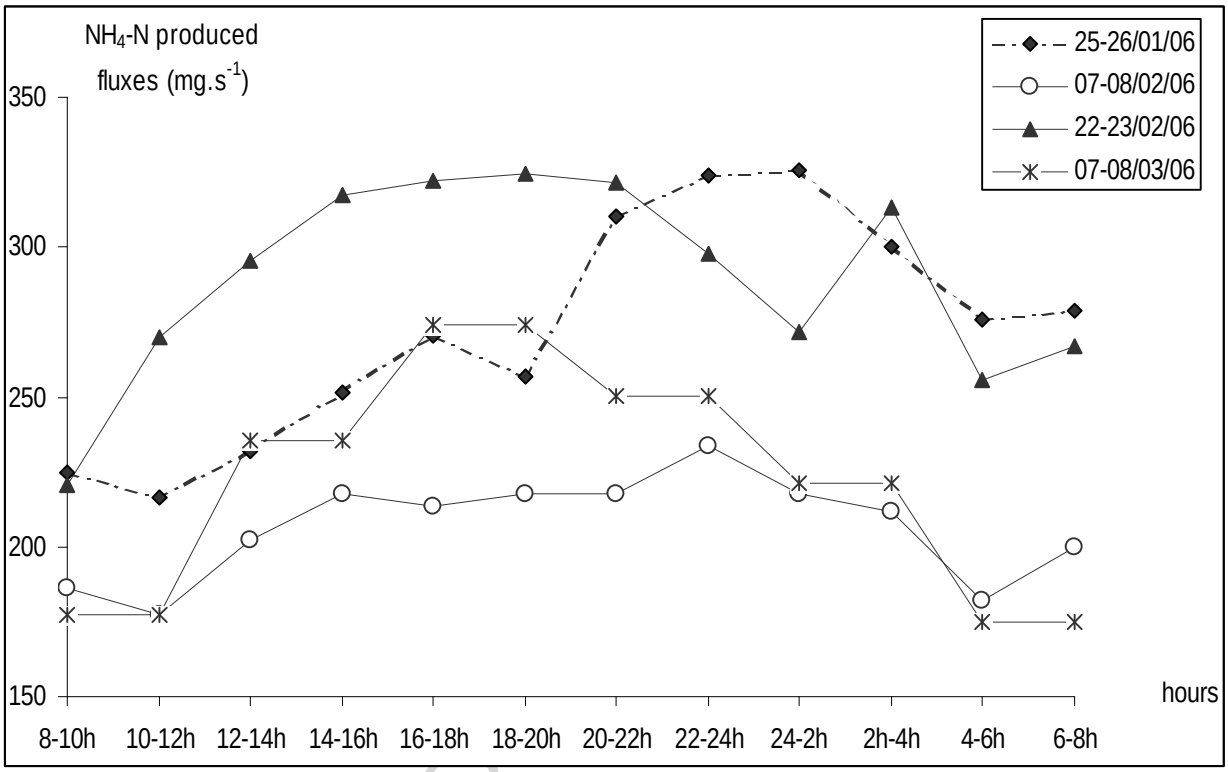

Figure 6. Daily fluctuations of the NH_4-N produced by the farm (sectors 1 & 2), for 3 different 24h sampling periods (1: 25-26.01.2006; 2: 07-08.02.2006; 3: 22-23.02.2006) and produced by the sector 1 only for the last date (06-07.03.06). The NH_4-N fluxes are expressed in mg per second.

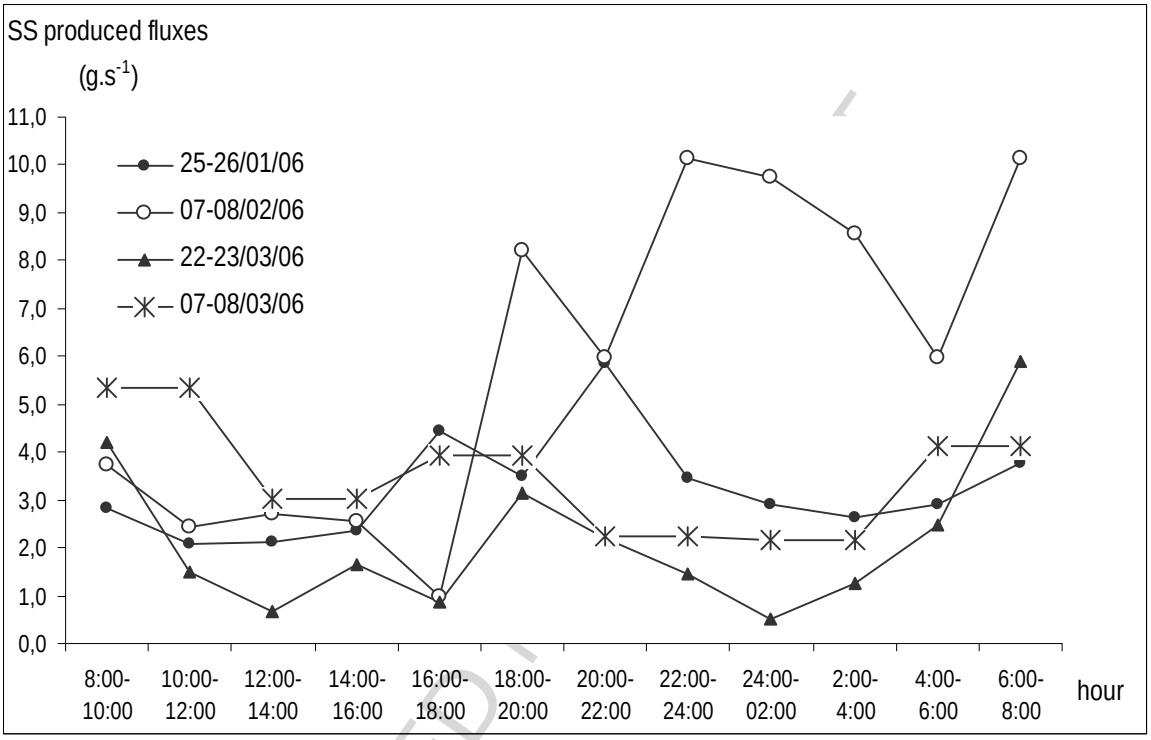

Figure 7. Daily fluctuations of the total suspended solids produced by the farm, for the first 3 24h sampling periods (1: 25-26.01.2006; 2: 07-08.02.2006; 3: 22-23.02.2006) and produced by the sector 1 for the last date (06-07.03.06). The TSS fluxes are expressed in g per second.

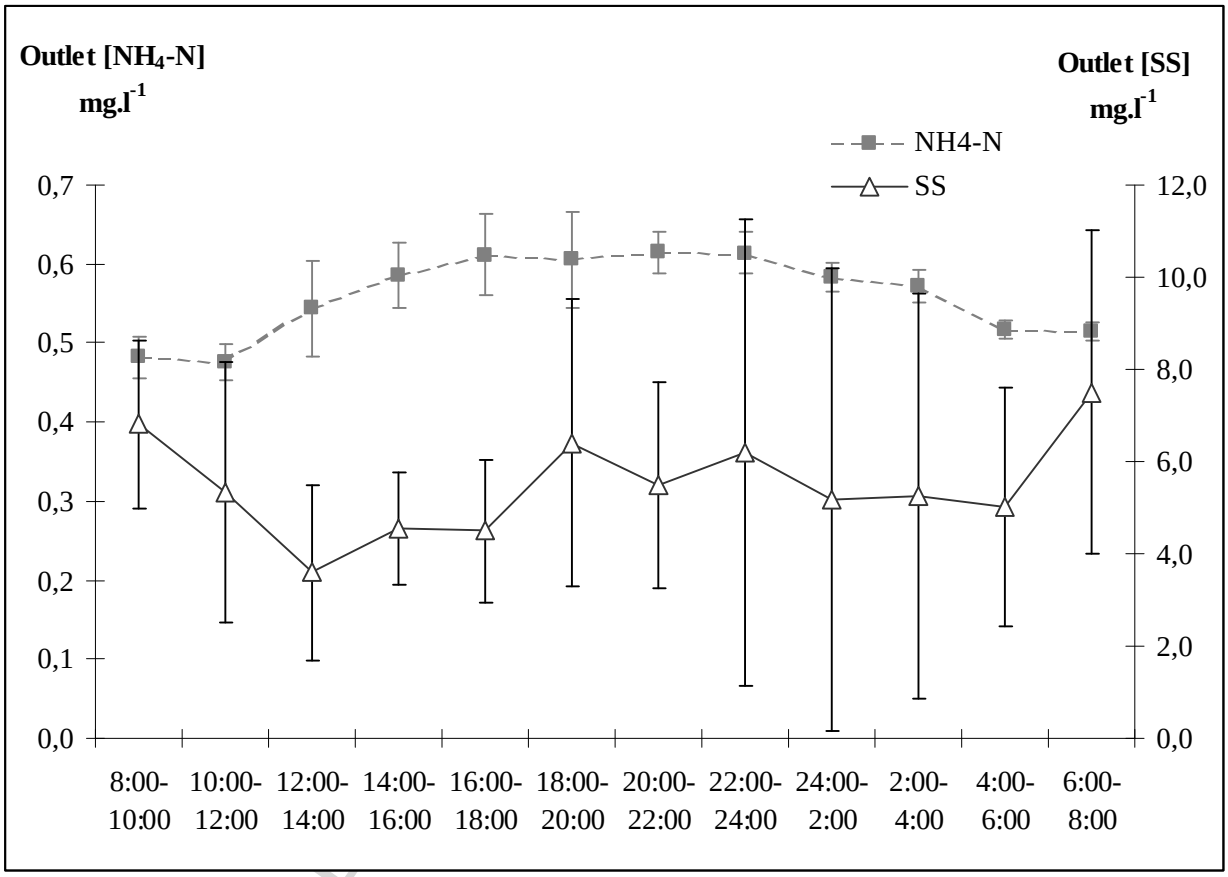

Figure 8. Averaged suspended solid and NH_4-N outlet concentrations (with standard deviations), measured at the outlet point of the farm, during four different 24h sampling periods. The concentrations are expressed in mg per litre.

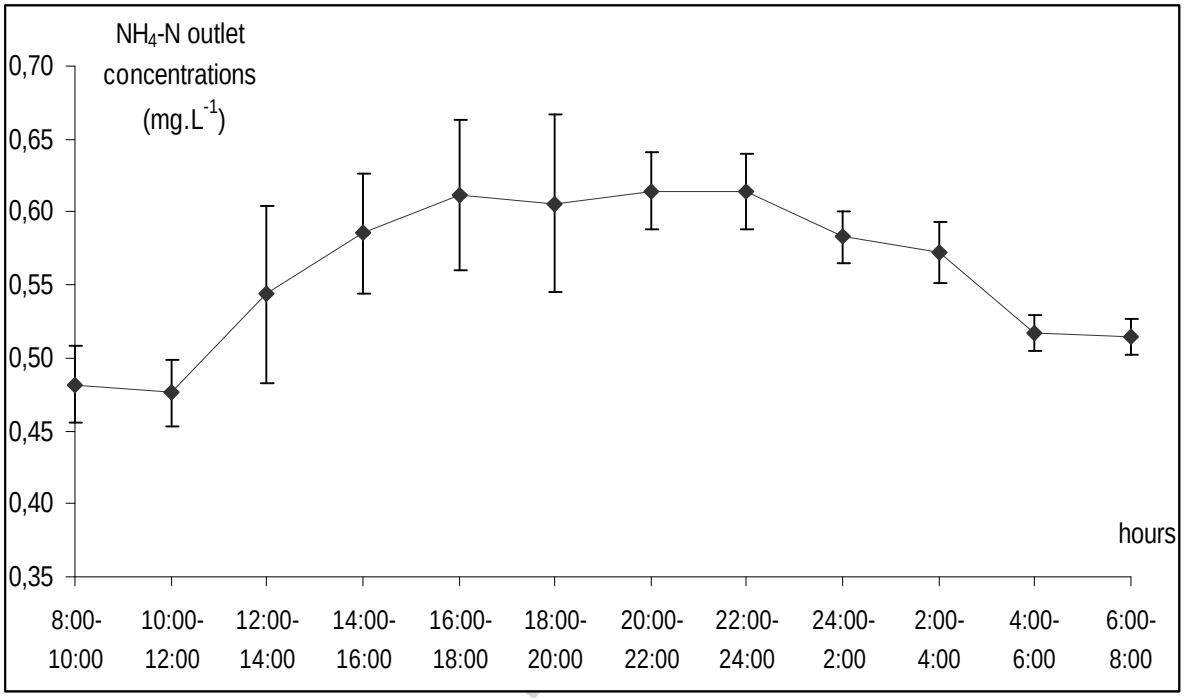

Figure 9. Averaged NH_4-N outlet concentrations (with standard deviations), measured at the outlet point of the farm, during four different 24h sampling periods. The concentrations are expressed in mg per litre.